Changes in science attitudes, beliefs, knowledge and physiological arousal after implementation of a multimodal, cooperative intervention in primary school science classes

ABSTRACT

Purpose. Student competency in science learning relies on students being able to interpret and use multimodal representations to communicate understandings. Moreover, collaborative learning, in which students may share physiological arousal, can positively affect group performance. In the present study, changes in student attitudes and beliefs, physiology (electrodermal activity; EDA) and content knowledge were observed before and after a multimodal, cooperative inquiry, science teaching intervention to determine associations with productive science learning and increased science knowledge.

Method. A total of 214 students with a mean age of 11 years 6 months from seven primary schools participated in a multimodal, cooperative inquiry, science teaching intervention for eight weeks during a science curriculum unit. Students completed a series of questionnaires pertaining to attitudes and beliefs about science learning and science knowledge before (time 1) and after (time 2) the teaching intervention. Empatica E3 wristbands were worn by students during 1 to 3 of their regularly scheduled class sessions both before and after the intervention.

Findings. Increases in EDA, science knowledge, self-efficacy and a growth mindset, and decreases in self-esteem, confidence, motivation and use of cognitive strategies, were recorded post-intervention for the cohort. EDA was positively correlated with science knowledge, but negatively correlated with self-efficacy, motivation and use of cognitive strategies. Cluster analysis suggested three main clusters of students with differing physiological and psychological profiles.

Practical implications. Firstly, teachers need to be aware of the importance of helping students to consolidate their current learning strategies as they transition to new learning approaches in order to counter decreased confidence. Secondly, teachers need to know that an effective teaching multimodal science intervention can not only be associated with increases in science knowledge but also increases in self-efficacy and movement towards a growth mindset. Finally, while there is evidence that there are positive associations between physiological arousal and science knowledge, physiological arousal was also associated with reductions in self-efficacy, intrinsic motivation and the use of cognitive strategies. This mixed result warrants further investigation.

Keywords: science learning, science attitudes, science beliefs, collaborative learning, science content knowledge, electrodermal activity

Highlights:

- Physiological arousal (electrodermal activity, or EDA), science knowledge and self-efficacy increased post-teaching intervention.
- EDA was positively correlated with science knowledge, but negatively correlated with self-efficacy, motivation and use of cognitive strategies.
- Three distinct student clusters show variance in physiological and psychological traits and these have differing responses to the teaching intervention.
- There is a need for countering decreased confidence when learning new strategies.
- More research is required to determine the potential utility of monitoring physiological changes in learning environments.

Word count: 6,868 words

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1. INTRODUCTION

Students need to be able to use and interpret different scientific representations such as models, diagrams, and tables (Rennie, 2005). They need to be able to understand how scientific ideas and concepts are represented and appreciate how scientific knowledge is constructed and validated (Prain and Tytler, 2013) if they are to be scientifically literate. Successful learning in science requires students to interpret and use different representations such as language, text, diagrams, tables, models, drawings, portfolios, and artefacts, as well as embodied forms of communication such as gesture, role play, facial expressions, mime, and exhibitions of performance. Moreover, students need to competently use, critique and explain representations as well as learn new representations quickly if they are to demonstrate meta-representational competence (diSessa, 2004). Waldrip *et al.* (2010) argue that the discipline of science should be seen as the integration of different modes (i.e., verbal, visual, and mathematical) to represent and communicate various understandings with students, in turn, learning about these multimodal representations (i.e., different types of representations) and how the same concepts of science can be represented in different modes.

In a review of the empirical evidence on scaffolding for science education, Lin *et al.* (2012) reported that there is now a major trend towards using multiple representations, including visualisations, social interactions among peers, written prompts to support students' conceptual understanding, procedural and strategic skills, metacognition and epistemology. In short, students need to be able to use multiple representations across a range of modalities. Multimodal representations range from figures and diagrams, to pictures, symbols, and equations. In arguing for an integrative framework for the analysis of multiple and multimodal representations for meaning-making in science education, Tang *et al.* (2014) propose that students need to be exposed to both multiple representations and multimodal representations simultaneously. In the former, the focus is on how science concepts can be re-represented in different ways (i.e., models, role plays, manipulatives) whereas in the latter, the focus is on how the components of a representation are integrated to produce understanding (e.g., language, visualisations, symbols). In effect, both types of representations are complementary in helping students to construct meaning in science.

Jornet and Roth (2015) reported on how a group of upper secondary students engaged in sense-making practices when they were confronted with multiple representations of scientific phenomena, in this case, a task from their science curriculum on energy. To understand learning from multiple representations, the authors argued that they needed to understand how the movement from form to *re*-presentation takes place in and through situated classroom transactions. In this study, the students were asked to investigate an artefact (heat pump), observe what happens, discuss their observations with each other, and make a small video with their i-Pods to illustrate and explain what they observed. By using interactional analysis (Jordan and Henderson, 1995) to analyse the videos, the authors were able to identify how the students used different social, bodily, and pragmatic aspects of communication (i.e., talk, nonverbal transactions, artefacts and technologies) with multiple representations to make sense of the science they were learning. In effect, the authors concluded that ‘understanding learning with multiple representations requires an understanding of the pragmatics of joint action, of how the body and the materials come to amalgamate as a unitary situation in the learner’s experience’ (p. 398); providing new understandings of how students learn from multiple representations and multiple modalities in classroom settings. Similar results were obtained by Nam and Cho (2016) who found that students’ writing and conceptual understanding in science improved significantly as a consequence of learning how different multimodal representations could be represented, interpreted, and applied to communicate their understandings of scientific concepts.

Wilson and Bradbury (2016) reported on how two first grade teachers taught a science unit on carnivorous plants using a multimodal 5E model of inquiry (Bybee, 2006) that engaged the students in using a variety of semiotic tools; such as, viewing physical specimens, viewing videos, and reading, writing, and drawing about these plants. In addition, the students were also involved in developing models, including multiple representations of the Venus Fly Traps (VFTs), analysing and interpreting data, and obtaining, evaluating and communicating information. Analysis of the students writing and drawing indicated that the students increased their knowledge of the VFT structure and function and synthesised information from multiple sources.

Research on student learning also indicates that the characteristics of a specific setting such as the physical and social environments shape students' interpersonal and psychological processes, so students, in turn, become attuned to the affordance and constraints of the activity and the setting within which they operate (Greeno, 1998). It is by interacting with others both within and outside the group that understandings are constructed and identities and affiliations are formed which serves to motivate students to cooperate and adopt the practices common to the group (Chinn and Clark, 2013). Moreover, research suggests that collaborative experiences motivate students to achieve, with Xu and Du (2013) reporting that motivation in group work was positively related to student initiative, including arranging the environment, managing study time and help seeking in online collaborative group work. In fact, Kempler *et al.* (2013) found that students' level of self-efficacy within the group can potentially increase the quality of collaborative interactions and group performance.

More recently, studies have suggested that this collaborative engagement by students in the classroom may relate to shared physiological processes. A previous case study (Gillies *et al.*, 2016) indicated that a multimodal, cooperative inquiry science teaching intervention was associated with high levels of common engagement during whole class activities and student-centred learning during cooperative group activities, as indicated though synchrony of electrodermal activity (EDA; also known as galvanic skin response or GSR) across students. In addition, Dikker *et al.* (2017) used a portable electroencephalogram to monitor brain activity in 12 high school students during 11 of their regular classes and proposed that group neural synchrony correlated with social dynamics and classroom engagement. These studies provide evidence that observing changes in physiological arousal markers as a quantitative measure may have some utility in predicting shared attention or connectedness in the classroom.

The purpose of the present study was to explore physiological and psychological changes in primary school students following exposure to a multimodal, cooperative inquiry, science teaching intervention, to determine how they may be associated with productive science learning and increased science knowledge. Psychological constructs of interest in this study centre around students' attitudes and beliefs about science learning and their perceptions of their own capabilities as learners. Self-efficacy, growth mindset, confidence, self-esteem, motivational beliefs and use of cognitive strategies are important psychological constructs to measure as they can assist teachers to improve how they interact and work with students. Examination of physiological changes is focused on measures of arousal, as captured through EDA. It is anticipated that the findings of this study will add to our understanding of both the physiological and psychological changes that may characterise the learning process in students, ultimately informing how we can optimise learning environments for students.

2. METHOD

2.1 Participants

Participants were 214 students from across 22 classes (grade six and seven) from seven primary schools who participated in one of two trials of a multimodal, cooperative inquiry, science teaching intervention. For the present study, the effective sample comprised students who had complete data before (time 1) and after (time 2) the teaching intervention across all key measures – physiological arousal, attitudes and beliefs about science learning, and science knowledge. While the total sample for the two trials was 526, the effective sample for the current study comprised 214 students, of which 60.7% were male and 39.3% were female. The sample was almost evenly split over the two trials, with 45.3% of students in the sample having participated in the first trial and 54.7% having participated in the second trial. Ages of students in the sample ranged from 10 to 13 years with a mean age of 11 years and 6 months (SD = 0.54).

The subsample of 214 students was compared with the remaining sample (the 526 students who participated in the teaching intervention but did not have complete measures), to examine whether the subsample differed demographically from the total sample in any significant ways. T-tests revealed no significant differences in mean age between the subsample used in the present study (M = 11.64) and the remaining sample (M = 11.65) (t (448) = .282, *p*=.778). The gender distribution of students between the subsample (60.7% male, 39.3% female) and the remaining sample (65.0% male and 35.0% female) did not differ significantly (χ^2 (1, N = 451) = .863, *p* = .353). Moreover, a t-test examining differences in science knowledge scores prior to the delivery of the teaching intervention demonstrated no significant differences in science knowledge at baseline between the subsample (M = 123.71) and the remaining sample (M = 123.81) (t (383) = .137, *p* = .891).

2.2 Measures

2.2.1 Science knowledge

The Progressive Achievement Test (PAT) in Science (Martin *et al.*, 2009) is a standardised group test designed to inform teachers on the level of achievement attained by students in acquiring the concepts, skills, and processes of scientific knowledge. It covers a range of difficulties suitable for different age and grouping levels, with the items having a curriculum focus, representing the key strands of science (living systems, physical systems, earth and space systems, and chemical/material systems). Students' raw scores are converted to Rasch-scaled scores, which place students' numerical scores on a single scale of achievement, allowing for comparisons among different students. Percentile ranks and stanine scores allow for comparisons between students' performances and a national Australian reference group. Students who participated in the present study completed the PAT Science before (i.e., late in term one) and after (i.e., end of term three) the intervention. The converted Rasch-scaled scores were used to capture progress in students' science achievement as a consequence of having participated in the two inquiry-based science units.

2.2.2 Attitudes and beliefs towards science learning

Academic Self-Description Questionnaire (ASDQ–I). The *ASDQ–I* (Marsh, 1990) measures multiple dimensions of how pre-adolescents perceive their academic competence (self-concept) across multiple subject areas. In the present study, Science self-concept (5 items; e.g., 'I learn things quickly in Science') and self-concept related to School Subjects in general (5 items; e.g., 'Work in most school subjects is easy for me') were used. Negatively worded (reverse scored) items were excluded from the sub-scales on the request of the schools. For each item, participants rated how true the statement described their belief on a 6-point scale ranging from 1 = Definitely False, to 6 = Definitely True. Psychometric properties of the instrument have been consistently sound (Marsh, 1990) and internal reliability for the present study were good, with Cronbach's alpha for the subscales as follows: Science self-concept α = 0.87; School Subject self-concept α = 0.89.

Children's Self-Efficacy Scale. Self-efficacy represents an individual's belief in his/her level of capability to execute a designated activity. In the present study, Bandura's *Children's Self-Efficacy Scale* (Bandura, 2006), which has 10 items of a self-efficacy for self-regulated learning subscale, was used to measure children's perceived capability to complete academic tasks in a self-regulatory manner. A six-point response format, ranging from 1 'Cannot do it at all' to 6 'Highly certain I can do it' was used to gain participants' perceived confidence in their ability to accomplish tasks, for example, 'take note of what is happening during the lesson'. In the present study the Cronbach's alpha for the subscale was good at α = 0.90.

Theory of Intelligence Scale. This scale was adapted from Blackwell *et al.* (2007) to focus specifically on science ability. The original 8 item scale was reduced to 7 items to improve reliability – all seven items reflect entity theory rather than incremental theory statements (e.g., 'You have a certain amount of intelligence, and you really can't do much to change it'). The seven items were reverse scored, so that a high value indicated agreement with incremental theory or growth mindset and a low value indicated agreement with a pure entity or fixed mindset. In the present study the Cronbach's alpha for the subscale was sound at α = 0.68.

Motivated Strategies for Learning Questionnaire (MSLQ). (Pintrich *et al.*, 1993) is a 44-item questionnaire composed of two major sections. The first, Self-regulated learning strategies, can be further divided into Cognitive Strategy Use items such as rehearsal, elaboration, and organization and Self-Regulation items such as metacognitive strategies and effort management. Motivational beliefs are further divided into Confidence items regarding perceived competence and confidence in performance of class work, Intrinsic Value concerning intrinsic interest in and perceived importance of work and preference for challenging goals, and Test Anxiety concerning worry and intrusion of cognitive thoughts during test taking. For the present study, 12 self-regulated learning strategies and 12 motivational belief items were chosen based on the findings of previous studies (Artino, 2005; Pintrich and De Groot, 1990). Participants responded on a six-point scale ranging from 1 ‘Not at all true of me’ to 6 ‘Very true of me’. This well-established scale has been found to be psychometrically sound (Artino, 2005; Pintrich *et al.,* 1993) with Cronbach’s alpha for the subscales in the present study as follows: Cognitive Strategy Use α = 0.70; Self-regulation α = 0.65; Confidence α = 0.85; Intrinsic Motivation α = 0.75; Test Anxiety α = 0.81.

2.2.3 Physiological monitoring

EDA in the present study was used to measure the physiological reactivity (changes in physiological arousal) of individual students within each lesson. Recorded data were included in the analysis if maintained for a minimum of 70% of the lesson time and signals were filtered offline for smoothing using high- and low-pass Butterworth filters to .01 – 1Hz. We calculated the root-mean square (RMS) of each individual student’s filtered EDA signal for the length of each lesson. Where x represents the EDA sample at time n, RMS for each student was calculated as $EDA_{rms} = \sqrt{\frac{1}{n}\left(x_1^2 + x_2^2 + x_3^2 \ldots + x_n^2\right)}$. The RMS value for a given student’s EDA signal represents their mean skin conductance level over the recording session weighted by the variability in the signal, giving a measure of the overall physiological reactivity of the student.

RMS values for each student were averaged across the sessions recorded before (time 1) and after (time 2) the teaching intervention. Time 1 and time 2 values were calculated from

1-3 sessions, depending on the number of recording sessions in which the student was present and provided consent (Time 1 M=2.55 sessions, SD=.60; Time 2 M=2.31 sessions, SD=.71).

2.3 Science Teaching Intervention

All teachers participated in three days of professional learning workshops that provided them with the background information on the two inquiry-based science units from the Australian Curriculum-Science (Australian Curriculum and Reporting Authority; ACARA, 2016) that they had agreed to teach. The units for the Year 6 teachers were based on the Science Understanding content descriptions in the Biological Science and the Earth and Space Science strands while the units for the Year 7 teachers were drawn from the Biological Sciences, the Chemical Sciences, Earth and Space Sciences, and the Physical Sciences in the Understanding Science strand.

As the Australian Curriculum-Science has a focus on teaching through inquiry, emphasis during the professiona learning workshops was attached to ensuring teachers were familiar with the 5E's model for teaching inquiry which emphasises the importance of engaging students' interests in the phenomena under investigation and helping them to engage, explore, explain, elaborate, and evaluate the information they have investigated (Bybee, 2006). The importance of students working cooperatively together in small groups to share ideas, challenge different conceptions and misconceptions, and clarify understandings along with the role of dialogic approaches such as Exploratory Talks (Mercer and Littleton, 2007) in helping students to reason and problem solve together were also emphasised (Slavin *et al.,* 2014). Finally, the role of different multimodal representations (i.e., using different types of visual [models, visualisations, media, text, concept maps, portfolios], auditory [domain-specific languages, discourse], kinaesthetic [exhibitions of performance, artefacts, constructions], and tactile modes [embodied gestures]) in teaching science were emphasised because of the importance of using multimodal representations to help students construct deeper understandings of science concepts (Hand *et al.*, 2016). For example, in the unit Earthquake Explorers: Earth and Beyond (Australian Academy of Science, 2009a), teachers used a variety of multimodal representation such as models of the earth's tectonic plates to understand earth movements, timelines using paper to understand time, maps of the earth to identify the tectonic plates, and the construction of a simple seismometer to demostrate te small and strong waves an earthquake produces.

All science units were augmented with resources from Primary Connections (Australian Academy of Sciences, 2009a) and Science by Doing (Australian Academy of Science, 2009b) and teachers were encouraged to support students to produce multi-modal representations of their understandings by using different visual (i.e., TWHL charts [what we think; what we know; what we want to learn; what we learned, and how we know], story boards, pictures, plasticine models, tables), auditory (i.e., auditory stories, personal narratives), and kinaesthetic representations (i.e., plasticine models, constructions, dioramas). Each science unit ran for eight weeks once a term for two consecutive school terms.

During the professional learning workshops emphasis was given to the importance of engaging students in cognitively challenging tasks (Cohen, 1994), asking for explanations and providing reasons (Mercer and Littleton, 2007), posing questions that challenged and scaffolded students' learning (Gillies, 2004), and promoting higher-order thinking (King, 2008). Emphasis was also attached to ensuring that cooperative group learning was structured so that students were interdependently linked and understood that they could not succeed in attaining the group's goal unless all group members contributed. That is, students understood that they needed to exercise appropriate social behaviours when interacting with their peers; all students were individually accountable for contributing to the group's effort to complete the task; and, all students need to engage in assisting their peers to contribute to the group's task (Johnson and Johnson, 2002).

In order to ensure uniformity across the process in teaching the inquiry science units, participating teachers were asked to adopt the following steps when introducing the different science lesson (adapted from Primary Connections, Australian Academy of Sciences, 2009a): 1. Try to spark students' attention and stimulate their curiosity in a topic through the introduction of a novel experience (e.g., role plays, videos, pictures, models, vignettes) which they discuss with the whole class; 2. Provide opportunities for students to work in their small groups (usually about 15-20 minutes) to explore the phenomena under investigation in more depth through different hands-on experiences (e.g., computer searches, brainstorming ideas, construct concept maps); and 3. Encourage students to identify patterns and relationships in the topic under investigation and develop scientific explanations for what they see, and share them with the wider class. Emphasis was placed on the cyclic nature of these steps so that during one lesson, the students may go back several times to explore the phenomena before they were satisfied with the explanations they had developed. Finally (perhaps after a number of science lessons), students were encouraged to reflect on their learning journey and create a report, portfolio, diorama or another product to demonstrate their new conceptual understandings of the phenomena they had been investigating.

2.4 Procedure

Ethics approval was obtained from the administering organisation and participating stakeholders as well as the principals of the schools involved in the study. Written informed consent to be involved in the study was obtained from the parents/guardians of participating students as well as the students themselves. The seven participating primary schools had expressed an interest in being involved in the study because of their commitment to teacher professional learning in teaching the new Australian Curriculum-Science that was being implemented in their schools.

All pre- and post-assessment instruments were administered by the researchers during regular class time; on average each took 45–60 minutes to complete at each time point. The intervention was delivered over an eight-week period across two school terms (total intervention = 16 weeks) with the Time 2 assessments being administered within 2 weeks of program completion. Empatica E3 wristbands (Empatica Inc., Milan, Italy) were fitted to individual students by researchers prior to 1 to 3 of their regularly scheduled class sessions (depending on attendance and consent) both before and after teacher intervention. These wireless biometric recording devices measured EDA continuously throughout the lesson at a sampling rate of 4Hz.

2.5 Statistical Analysis

All data analysis was undertaken using IBM SPSS version 24. As a first step, repeated measures ANOVA was used to examine changes over time in the key measures, namely physiological arousal, science learning beliefs and attitudes, and science knowledge. To understand how these factors may contribute to learning processes, change scores were calculated for all key variables and relationships between changes across the key variables were explored through a series of Pearson’s bivariate correlations.

2.5.1 *Cluster Analysis*

Variables that demonstrated statistically significant ($p<0.05$) associations across the nexus of psychological predispositions to science learning, physiological arousal, and science knowledge growth were selected as inputs for a cluster analysis to identify how these relationships were distributed across students. A two-step cluster analysis was undertaken which applies two processes to arrive at an ideal clustering solution. Firstly, pre-clustering is undertaken based on distances of a new case from subsequent cases or clusters. Following this, hierarchical clustering is undertaken on the pre-clusters, with the Schwarz Bayesian Criterion (BIC) or the Akiake information criterion used to determine the optimal clustering solution. For the current analysis, the BIC was chosen as the criterion for selecting the optimal clustering solution, and the following input variables were entered into the two-step cluster analysis: PAT Science change scores, EDA arousal change scores, total efficacy change scores, changes in cognitive strategies used, confidence change scores, and intrinsic motivation change scores. As noted previously, variables were selected which showed significant relationships across the nexus of physiological arousal, psychological predispositions to science learning, and changes in science knowledge. The classification of students resulting from this analysis was then assessed through a MANOVA, to examine how well the classification explained differences in change scores on key variables.

3. RESULTS

Table 1 displays a summary of the time 1 and time 2 means and change scores (time 2 minus time 1) on physiological arousal, the PAT Science test and science learning attitudes and beliefs measures for the cohort of 214 students. The results of the repeated measures ANOVA reveal some interesting changes over time across the various indicators, with physiological arousal significantly increasing from the first set of readings (time 1) to the second set of readings (time 2) ($F(1,213) = 20.462$, $p = <.001$, $\eta^2 = .088$), along with science knowledge ($F(1,213) = 39.637$, $p <.001$, $\eta^2 = .157$) , self-efficacy ($F(1,213) = 17.782$, $p <.001$, $\eta^2 = .077$), and the presence of a growth rather than fixed mindset ($F(1,213) = 4.529$, $p =.034$, $\eta^2 = .021$). Conversely, a number of the other survey measures decreased over this period, including self-esteem ($F(1,213) = 4.883$, $p =.028$, $\eta^2 = .022$), confidence ($F(1,213) = 4.081$, $p =.045$, $\eta^2 = .019$), intrinsic motivation ($F(1,213) = 14.394$, $p <.001$, $\eta^2 = .063$), and the use of cognitive strategies ($F(1,213) = 7.041$, $p = .009$, $\eta^2 = .032$).

[Table 1 near here]

In order to further explore how changes in physiological arousal might be related to changes in science knowledge and increases and decreases across a range of science learning attitudes and beliefs, a series of Pearson's bivariate correlations were undertaken on change scores for each of the indicators, calculated by deducting time 2 values from time 1 values (see Table 2). Hence, positive change scores indicate an increase in the variable from time 1 to time 2, and negative scores indicated a decrease in the variable from time 1 to time 2.

[Table 2 near here]

As we were interested in particular in the association between changes in physiological and psychological processes, and changes in science knowledge, variables were selected for further exploration if they demonstrated significant relationships across the nexus of physiological measures of arousal, survey measures of students' attitudes and beliefs about science learning, and changes in science knowledge. Looking firstly at physiological arousal (EDA), there was a positive correlation between changes in science knowledge and changes in arousal ($r = .141$, $p < .05$). There were also a number of negative associations between physiological arousal and some of the survey measures, including for self-efficacy ($r = -.172$, $p < .05$), intrinsic motivation ($r = -.139$, $p < .05$), and cognitive strategies ($r = -.186$, $p < .01$). In terms of increases in science knowledge, aside from the relationship with physiological arousal, the only other significant relationship was a positive correlation with confidence ($r = .151$, $p < .05$).

These relationships provide a somewhat mixed picture of the association in changes in students' physiological arousal, their attitudes and beliefs about science learning, and the growth in their science knowledge over the course of exposure to a science teaching intervention. Physiological arousal appears to be significantly associated with science knowledge gains, but also to reductions in self-efficacy, intrinsic motivation and the use of cognitive strategies. At the same time, increases in science knowledge are associated with increases in confidence. These findings suggest that perhaps there were not simply a uniform set of processes occurring within the sample of students, but rather that sub-groups of students within the sample may be experiencing different associations between changes in arousal, science learning attitudes and beliefs, and growth in science knowledge. To explore this further, a cluster analysis was undertaken to identify meaningful subgroups of students who had similar changes in physiological and psychological changes and changes in science knowledge.

The two-step cluster analysis generated a three-cluster solution (i.e. 3 clusters with students in each cluster sharing similar characteristics for the input variables), with cluster 1 comprising 52.8% of the sample, cluster 2 comprising 32.2% of the sample and cluster 3 comprising 15% of the sample. Figure 1 shows the means of each of the key input variables for the clusters. Cluster 1 demonstrated the lowest increase in physiological arousal, the second highest increase in science knowledge, the largest increase in self-efficacy, confidence, use of cognitive strategies and intrinsic motivation. Cluster 2 was characterised by a median increase in physiological arousal across the groups, the largest increase in science knowledge, a small increase in self-efficacy, and reductions in confidence, cognitive strategies used, and intrinsic motivation. Cluster 3 had the largest increase in physiological arousal, a small reduction in science knowledge, and relatively large reductions in self-efficacy, confidence, cognitive strategies used and intrinsic motivation.

[Figure 1 near here]

A MANOVA was undertaken to examine how well the clusters predicted variance in the input variables. The findings indicated that the clusters had significantly different means across all the input variables, as can be seen in Table 3. Post hoc analyses using Fisher's least significant difference (LSD) was used to identify significant differences between individual cluster means. Cluster 1 differed significantly from Cluster 3 on changes in physiological arousal, but not with Cluster 2, while Cluster 2 also differed significantly with Cluster 3 on physiological arousal. In terms of changes in science knowledge, there was a trend towards a significant difference between cluster 1 and cluster 2 (p = .055), and no significant difference between cluster 1 and cluster 3. Cluster 2 and 3 differed significantly in terms of changes in science knowledge. For mean changes in self-efficacy, confidence, cognitive strategies used and intrinsic motivation, all clusters differed significantly from one another.

[Tables 3 and 4 near here]

In order to better understand the demographic profiles of the students in each of these clusters, ANOVA and chi-square analyses were undertaken to determine any differences in age, gender, levels of science knowledge prior to being exposed to the teaching intervention, and changes in implicit beliefs, i.e. changes indicating movement towards a growth mindset. The findings can be seen in Table 4. There were no significant differences in age and gender, or in changes in movement towards a growth mindset, across the groups. There was, however, a trend towards significance for differences in baseline science knowledge (p = .054), with Cluster 3 showing a higher level of mean science knowledge than the other groups.

4. DISCUSSION

A primary aim of this study was to understand how changes in physiological arousal and psychological predispositions to science learning may be correlated following exposure to a best practice science teaching intervention, and how they may be associated with productive science learning resulting in increased science knowledge. To assist students to gain full understanding of scientific ideas and knowledge, a combination of the mode of presentation of the science concepts and promotion of collaborative learning was considered as a teaching intervention. Exposure to a multimodal, cooperative inquiry, primary science teaching intervention was associated with a mean increase in science knowledge, as would be anticipated in a general period of teaching whether there was an intervention or not. It was also associated with mean increases in self-efficacy and a movement towards a growth mindset, which both have positive effects on student perseverance and motivation to learn and succeed (Greene, 2018; Hochanadel and Finamore, 2015). On the other hand, there were mean decreases in general self-esteem, confidence, intrinsic motivation and cognitive strategies used. Potential reasons for this are discussed below.

There was a mean increase in physiological arousal from pre- to post-intervention and significant positive associations were evident between physiological arousal and science knowledge, however physiological arousal was also associated with reductions in self-efficacy, intrinsic motivation and use of cognitive learning strategies. Physiological arousal has been found in a previous case study (Gillies *et al.*, 2016) to be associated with increased connectivity to other students during a similar science teaching intervention. However, while arousal may indicate productive cognitive engagement with a learning task, it may also indicate students experiencing anxiety. As there are a variety of measurable qualities to describe physiological arousal in addition to EDA (such as blood pressure, heart rate and rate of respiration), a more thorough investigation including these and other metrics would be required for a deeper understanding of these findings.

In particular, the mixed relationship between physiological arousal and productive learning in a science learning context is worthy of further exploration. One possible mechanism to explain the results presented in this study is that moderate increases in EDA potentially indicate the effective deployment of cognitive resources to deal with a higher cognitive load, while higher levels indicate a level of arousal or anxiety that may actually interfere with productive learning. While there has been little research to date on how physiological indictors of arousal change with academic performance, Vogel and Schwabe (2016) reviewed the impact of acute stress on memory and learning, highlighting the implications for the classroom. This includes discussion on positive (light) versus negative (heavy) levels of stress, which is not distinguishable via EDA alone. Another point of interest is that different individuals have varying coping strategies that would affect their level of arousal and academic performance.

A cluster analysis to further investigate the conflicting associations between physiological and psychological observations indicated that three distinct classes of students could be discerned, with differences between these clusters in changes in physiological arousal, science knowledge, self-efficacy, confidence, use of cognitive strategies and intrinsic motivation. These results indicated that the majority of students experienced an increase in science knowledge, with cluster 1 and 2 collectively accounting for 85% of the sample. These two clusters also experienced relatively small increases in physiological arousal over time. Interestingly, while cluster 2 experienced the largest mean increase in science knowledge, and showed a small increase in self-efficacy, this cluster also demonstrated reductions in confidence, use of cognitive strategies, and intrinsic motivation. This may indicate that these students were exposed to learning processes that made them more aware and perhaps critical of the deficiencies or shortcomings in their existing repertoire of cognitive learning strategies and left them feeling a reduced sense of confidence and motivation towards science learning, though in fact their science knowledge grew over this period. Huber *et al.*, (2015) similarly described a group of students who self-underestimated their abilities in spite of being high achievers, and further suggested that these students have lower internal learning processes than students with a high self-concept.

Cluster 3, comprising 15% of the sample, was the only group that demonstrated a small mean reduction in science knowledge, and also had the largest mean increase in physiological arousal. Interestingly, this cluster showed a trend towards having higher mean science knowledge prior to exposure to the teaching intervention, and so may reflect students who had fairly well-established cognitive strategies and learning routines to assist them in tackling science learning tasks. This group was the only group that had a (fairly large) reduction in self-efficacy, alongside relatively large reductions in confidence, use of cognitive strategies and intrinsic motivation. Students who are highly adept in managing traditional science learning contexts, which may involve more passive consumption of information and greater teacher directed learning, may find the changes to the learning contexts most challenging, as they feel their existing, well-developed strategies become somewhat redundant in the new learning environment. Thus, it may be important for teachers using similar teaching interventions to implement assimilating strategies to ensure that students demonstrating the characteristics of this cluster do not struggle with confidence.

In this study observing physiological and psychological changes during a teaching intervention, several limitations must be acknowledged. A lack of a control or comparator groups makes attribution of changes to the particular teaching intervention challenging, and as such, the findings of this study are indicative of observed associations over the period of exposure, which may or may not reflect the particular characteristics of the teaching intervention. Causal relationships or even directional associations between changes in physiological arousal, science learning attitudes and beliefs, and science knowledge cannot be inferred purely from the findings of the present study. The sample size was relatively small, which resulted in limited power to detect small between group differences. Finally, changes in physiological arousal due to stress, engagement or both cannot be distinguished using EDA alone.

The purpose of this study was to observe the changes in student physiological arousal after implementation of a multimodal, cooperative inquiry science intervention, and to analyse the relationships between changes in attitudes and beliefs and science knowledge with respect to increased science learning and knowledge. Given the reduction in areas of confidence, self-efficacy and motivation post-intervention, teachers using these kind of teaching approaches may need to prepare for and counter these initial reactions from students, as students may feel their existing learning strategies are no longer effective. For example, teachers could potentially transition in new learning approaches so that students can still use some of their existing learning strategies as they begin to develop and consolidate new learning strategies. In addition, a more in-depth analysis of how changes in different physiological markers such as EDA relate to science learning and knowledge is required. Further exploration of optimal level of arousal or cognitive load for productive learning may be of value, which may enable teachers to modify tasks to ensure they are well-pitched to maintain students’ confidence and motivation at the same time as facilitating the development of more independent, active learning strategies.

4.1 Implications for research

Using and interpreting different multimodal scientific representations is challenging for many students because they need to be able to not only understand how science concepts are represented but how the different components of a representation can be integrated to produce understanding. Building these understandings is not easy, requiring teachers to not only help students consolidate their current learning strategies but also adopt new approaches to learning as they transition from the known to the unknown. Furthermore, while there is evidence that there are positive associations between physiological arousal and science knowledge, physiological arousal was also associated with reductions in self-efficacy, intrinsic motivation and the use of cognitive strategies. These mixed results warrant further investigation.

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Table 1: Time 1 and Time 2 means, differences scores, and p values for repeated measures ANOVA

Variables	**Time 1**	**Time 2**	**Difference**	***P****
EDA (physiological arousal)	.18	.37	.19	<.001
PAT Science test	123.71 (7.13)	126.64 (8.22)	2.93	<.001
Science self-concept	21.38 (4.09)	21.24 (3.73)	-.14	.587
School self-concept	22.05 (4.45)	21.60 (4.07)	-.44	.081
General self-esteem	18.71 (2.94)	18.33 (2.89)	-.38	.028
Self-efficacy	43.81 (9.42)	46.59 (10.69)	2.78	<.001
Confidence	17.23 (3.69)	16.80 (3.75)	-.43	.045
Intrinsic motivation	18.66 (3.34)	17.79 (3.75)	-.87	<.001
Test anxiety	11.70 (4.86)	11.56 (5.24)	-.14	.653
Cognitive strategies	26.17 (5.84)	25.02 (5.49)	-1.15	.009
Self-regulation	24.88 (4.58)	24.39 (4.79)	-.50	.115
Growth mindset	21.49 (5.16)	22.23 (5.28)	.75	.034

*Mean differences from Time 1 to Time 2 assessed using repeated measures ANOVA

Table 2: Pearson's correlations for difference scores on physiological, psychological and science knowledge indicators

	EDA	PAT Science scores	Science self-concept	School self-concept	General self-esteem	Self-efficacy	Confidence	Intrinsic motivation	Test anxiety	Self-regulation
PAT Science scores	.141*									
Science self-concept	.039	.046								
School self-concept	-.070	.066	.578**							
General self-esteem	-.040	.059	.502**	.619**						
Self-efficacy	-.172*	.064	.125	.244**	.168*					
Confidence	-.053	.151*	.446**	.431**	.452**	.450**				
Intrinsic motivation	-.139*	.012	.260**	.306**	.294**	.363**	.452**			
Test anxiety	-.072	-.092	-.132	-.210**	-.208**	.082	-.071	.030		
Cognitive strategies	-.186**	-.033	.172*	.237**	.298**	.472**	.480**	.465**	.063	
Self-regulation	-.022	.113	.231**	.174*	.247**	.259**	.398**	.385**	-.149*	

Growth mindset	.046	-.015	.039	-.037	-.088	-.120	-.120	-.087	-.143*	.068

*p<.05, **p<.01

Table 3: Means and results of MANOVA examining variance explained across input variables by the three cluster solution

Variables	**Cluster 1**	**Cluster 2**	**Cluster 3**	**P***	**LSD Post hoc analysis**		
N (%)	69 (32.2%)	113 (52.8%)	32 (15.0%)		Cluster 1 v Cluster 2	Cluster 2 v Cluster 3	Cluster 3 v Cluster 1
EDA arousal change M (SD)	.03 (.18)	.13 (.26)	.76 (1.36)	<.001	.249	<.001	<.001
PAT Science score change M (SD)	2.25 (6.57)	4.21 (6.06)	-.13 (8.62)	.003	.055	.001	.097
Total efficacy change M (SD)	10.61 (7.57)	.73 (7.12)	-6.91 (8.94)	<.001	<.001	<.001	<.001
Cognitive strategies change M (SD)	3.77 (3.97)	-2.38 (3.79)	-7.41 (9.48)	<.001	<.001	<.001	<.001
Confidence change M (SD)	2.20 (2.60)	-1.02 (1.95)	-4.03 (2.81)	<.001	<.001	<.001	<.001

Intrinsic motivation change **M (SD)**	1.96 (2.56)	-1.65 (2.31)	-4.19 (3.35)	<.001	<.001	<.001	<.001

* Between groups differences for clusters tested with MANOVA

Table 4: Differences between clusters in demographics, baseline science knowledge, change in growth mindset orientation

	Cluster 1	**Cluster 2**	**Cluster 3**	**P***
Age	11.72 (.52)	11.60 (.56)	11.58 (.49)	.282
Gender **% Female**	43.5%	39.8%	28.1%	.334
Time 1 PAT Science score	123.58 (7.60)	123.01 (6.56)	126.44 (7.57)	.054
Growth mindset change scores	.36 (5.08)	.70 (4.82)	1.75 (6.29)	.448

*Between group differences examined through univariate ANOVA and Chi-square analyses

List of Figures

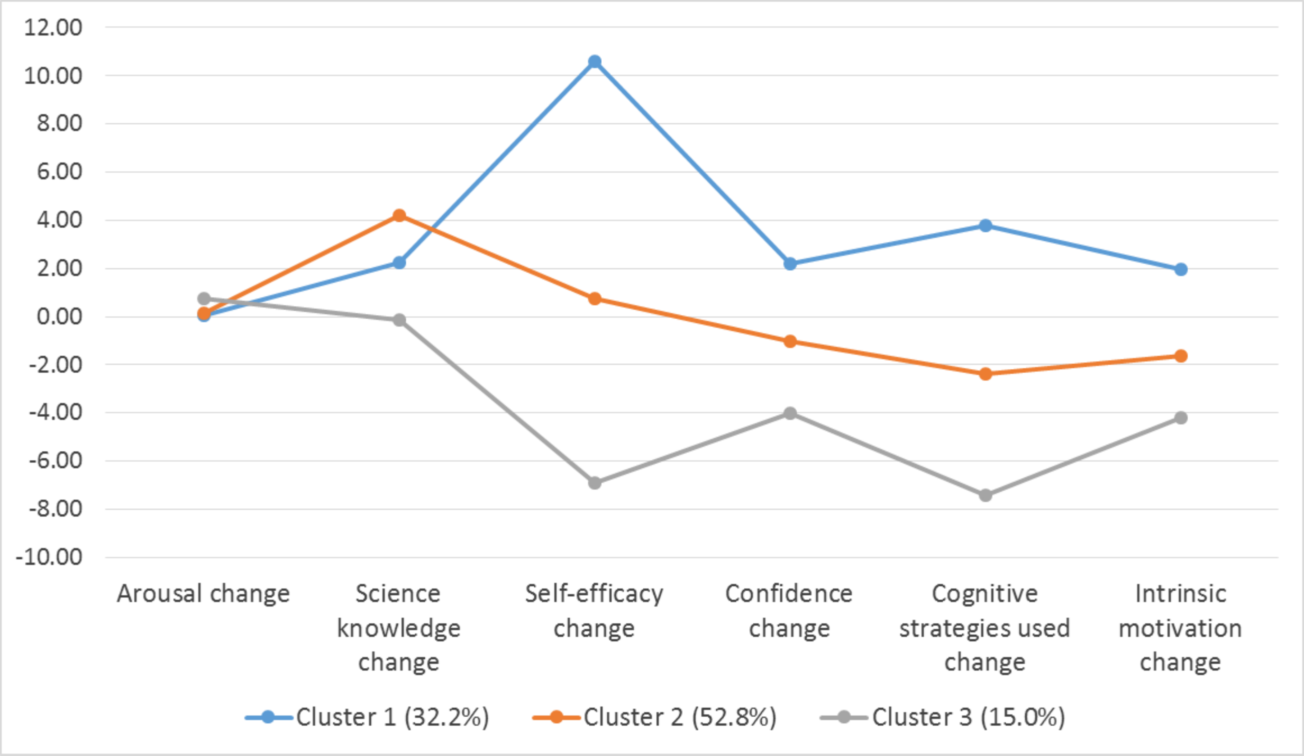

Figure 1: Means for change in physiological arousal, science knowledge, self-efficacy, confidence, cognitive strategies and intrinsic motivation across the three clusters